Project Introduction

NOTE: Continues "Computational Model for Spacecraft/Habitat Volume (Spacecraft Optimization Layout and Volume (SOLV))" with PI Dr. Sherry Thaxton due to Dr. Thaxton's move to Human Factors & Behavioral Performance Deputy Element Scientist, as of 2/5/2017.

A key design challenge for future long-duration exploration missions is determining the appropriate volume of a spacecraft/habitat to accommodate habitability functions and ensure optimal crew health, performance, and safety. Because spacecraft/habitat volume directly drives mass and cost, this information is needed early in the design process. This proposal is in response to the NASA Research Announcement (NRA) NNJ13ZSA002N A.2.i: Computational Modeling and Simulation for Habitat/Vehicle Design and Assessment, and it addresses the Human Research Program (HRP) Program Requirements Document (PRD) Risk of Incompatible Vehicle/Habitat Design. The objective of this proposal is to develop a constraint-driven, optimization-based model that can be used to estimate and evaluate spacecraft/habitat volume. The computational model development will be completed through four Specific Aims: Estimate spacecraft/habitat volume based on mission parameters and constraints, provide layout assumptions for a given volume, assess volumes based on a set of performance metrics, and inform risk characteristics associated with a volume.

To accomplish this, the proposed team has been structured to leverage expertise from diverse fields, including architecture and habitation design, human factors engineering, industrial engineering, optimization-based modeling, and simulation. The proposed work will also leverage technical products developed from the HRP-hosted 2012 Habitable Volume Workshop, as well as work performed in the follow-on exploratory project in 2013, including critical task volume estimations and input/output definitions for the computational model. Lessons learned from the development of the Integrated Medical Model (IMM) developed by the Exploration Medical Capability Element (ExMC) of the HRP will also be applied to the proposed work -- lessons ranging from model development approach to compliance with NASA STD 7009, Standard for Models and Simulation. Model validation and verification will be a continuous process occurring throughout model development. The guidelines of NASA-STD-7009 will be followed in establishing parameters and vetting the credibility of the model at all stages of development. The outcome of the proposed work will directly answer to HRP's Risk of Incompatible Vehicle/Habitat Design and the associated Space Human Factors Engineering (SHFE) SHFE-HAB-09 Gap on technologies, tools, and methods for data collection, modeling, and analysis for design and assessment of vehicles/habitats. A computational model for spacecraft/habitat volume will be an invaluable tool for designers, mission planners, integrators, and evaluators who are shaping space habitats and working toward a truly habitable environment for future long-duration exploration missions.

Computational Model for Spacecraft/Habitat Volume (Spacecraft Optimization Layout and Volume (SOLV))--Chen

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Anticipated Benefits

Earth industries that are concerned with habitability in confined environments for long durations (e.g., shipping, submarines, oil and gas rigs, Antarctic research stations) may benefit from the task-based approach in development for determining overall volume needs.

Primary U.S. Work Locations and Key Partners
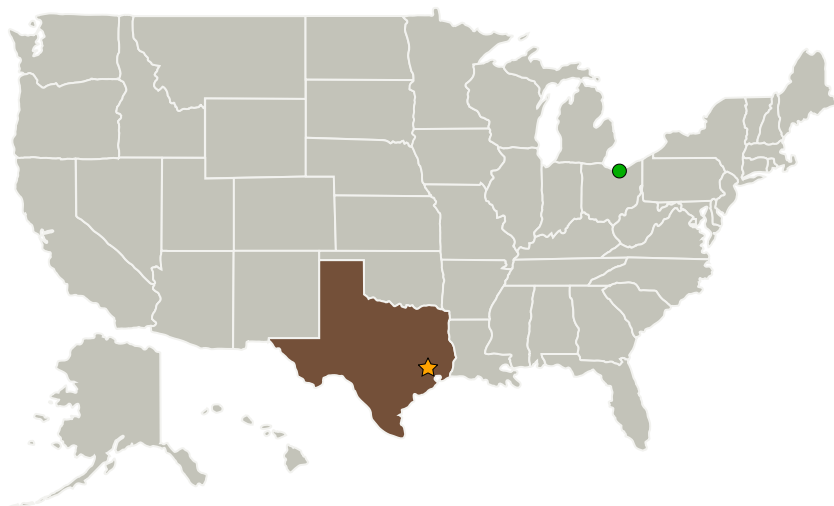
Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

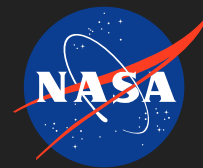**Project Manager:**

Thomas J Williams

Principal Investigator:

Maijinn Chen

Co-Investigators:

Jerry G Myers
Churlzu Lim
John D Arellano
Simon M Hsiang

| Organizations Performing Work	Role	Type	Location
⭐Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
🟢Glenn Research Center(GRC)	Supporting Organization	NASA Center	Cleveland, Ohio
KBRwyle, Inc.	Supporting Organization	Industry	Houston, Texas
MEI Technologies	Supporting Organization	Industry Small Disadvantaged Business (SDB), Veteran-Owned Small Business (VOSB)	
University of North Carolina at Charlotte	Supporting Organization	Academia	Charlotte, North Carolina

Primary U.S. Work Locations
Texas

Project Transitions

▶ **February 2017:** Project Start

Technology Maturity (TRL)

Start: **5**
Current: **6**
Estimated End: **6**

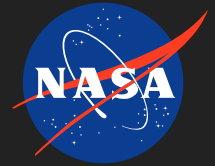| 1	2	3	4	5	6	7	8	9
Applied Research				Development		Demo & Test		
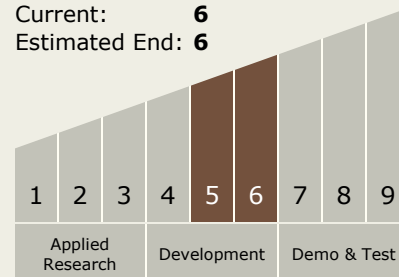
Technology Areas

Primary:

- TX11 Software, Modeling, Simulation, and Information Processing
  └ TX11.2 Modeling
    └ TX11.2.3 Human-System Performance Modeling

Target Destinations

The Moon, Mars

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✔ May 2018: Closed out

Closeout Summary: Work in Year 3 focused on SOLV data collection and analysis, code development, unit and system integration testing, and project documentation in preparation for delivery on May 31, 2018.Refinements were made to the Critical Task Volume Database in Year 3. Revision 3 of the database was released on 3/7/2018. Additional volume data were collected in the areas of Exercise, Recreation, Food Preparation, EVA Suit Don/Doff/Stowage & Maintenance, Mission-Specific Onboard Research, and Hatch Ingress/Egress.SOLV was using Analytic Hierarchy Process (AHP) surveys to collect subject matter expert (SME) opinions and judgments to establish a factor weighting and scoring system in order to drive the model logic for evaluating layout performance. Year 3 saw the completion of all three phases of data collection and analysis. These phases are:

- Factor Priority Survey
- Interactions Effect Survey
- Manual Layout Evaluation Survey

The Factor Priority Survey completed data collection and analysis in July 2017. 21 SMEs including 4 astronauts participated in the surveys, generating 39 AHP responses for analysis. The Interactions Effect Survey completed data collection and analysis in August 2017. 15 SMEs including 2 astronauts participated, generating 22 AHP responses for analysis. The Manual Layout Evaluation Survey completed data collection and analysis in November 2017. 13 SMEs including 2 astronauts participated, generating 78 AHP responses for analysis.Five major SME groups were identified for participation in the AHP surveys: • Human Factors (SF3/HRP SMEs and Researchers); • Behavioral Health and Performance (Senior Research Scientists); • Medical (Flight Surgeons, Researchers); • Subsystem Integration (Space Architects, ISS Subsystem Leads, Exploration/CCP Integrators); • Flight Operations (Crew Systems, Astronauts)Participants from each SME group were instructed to perform pairwise comparisons for one or more performance metrics that are within their area of expertise:

- Human Factor SMEs answered surveys for the Task Performance and Health and Well-Being metrics.
- Behavioral Health and Performance SMEs answered surveys for the Task Performance and Health and Well-Being metrics.
- Medical SMEs answered surveys for the Health and Well-Being and Safety metrics.
- Subsystem Integration SMEs answered surveys for the Vehicle Integration metric.
- Flight Operations SMEs answered surveys for all four metrics: Task Performance, Health and Well-Being, Vehicle Integration and Safety.

From the Factor Priority Survey, the team was able to identify the six top design factors believed to have the greatest impact to the "goodness" of a layout. From the Interactions Effect Survey, the team used the analysis results to inform the Choquet Integral calculations and build SOLV logic for layout evaluation. From the Manual Layout Evaluation Survey, the team performed data calibration and Canonical Correlation Analysis to establish a numerical relationship between the physical data of sample packing layouts and the psychophysical data on design goodness, in order to build a model response surface for future layout performance evaluation.In Year 3, the team completed code development for each of the SOLV modules:

- Gradient Cuboid Module - Converts task volume inputs into gradient cuboids with overlap allowable.
- Overlap Packing Module - Generates layouts of the gradient cuboids based on SOLV variables and constraints.
- Evaluation Module – Establishes the model weighting system and the model response surface via Canonical Correlation Analysis (CANCORR), and contains hard-codes of the Data Envelopment Analysis (DEA) and Choquet Integral (CI) functions that establish the model scoring system for layout evaluation.
- Scorecard Module – An assessment report or "scorecard" that provides performance scores and design information for every volume and layout solution generated by SOLV. This enables the user to compare options and choose the best starting point for design.
- Driver Code - Additional code and scripts that integrate the modules to enable smooth model functions from user input to scorecard output.

The team also completed verification testing of SOLV in Year 3. Verification of model computations was formally assessed at the module level. There were two parts to the verification testing: • Model Verification – Model was verified that it had been implemented to meet our key driving requirements. • Code Verification - Model computations at the module level were verified via incremental testing to ensure that mathematical operations do not result in significant numerical errors.The team derived from the SOLV Key Driving Requirements a set of functional test requirements each SOLV module must satisfy. The team also identified the required test steps to verify each test requirement. The level of testing was adjusted to the credibility goals defined per NASA-STD-7009A Standard for Models and Simulations. Both the test plans, requirements, and results were vetted through multiple team reviews. A common documentation format was developed to capture the test results. Verification testing was completed in the 2017-2018 time frame: • GC Module: 10/31/2017; • Overlap Packing Module: 12/19/2

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Stories

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/47170)

Project Website:

https://taskbook.nasaprs.com